Properties and Drivers of Plasma Irregularities in the High-Latitude Ionosphere Computed using Novel Incoherent Scatter Radar Techniques

L. V. GOODWIN[1,2*] AND G. W. PERRY[1]

*Email: lindsay.v.goodwin@njit.edu, (1) Center for Solar-Terrestrial Research, New Jersey Institute of Technology, Newark, New Jersey, USA, (2) Cooperative Programs for the Advancement of Earth System Science, University Corporation for Atmospheric Research, Boulder, Colorado, USA.

INTRODUCTION

- The ionosphere is filled with plasma density structures that alter radio wave propagation and degrade the performance of critical technologies.
- There is still uncertainty as to what the dominant scale-sizes of plasma density structures are, as well as their association with different driving mechanisms (such as solar variations).
- To resolve this, it is useful to consider density structures as a function of spatial frequency.
- **Goal: Use Advanced Modular Incoherent Scatter Radar (AMISR) observations to quantify the "irregularity spectra" of the high-latitude ionosphere with uniquely capable techniques.**

METHODOLOGY

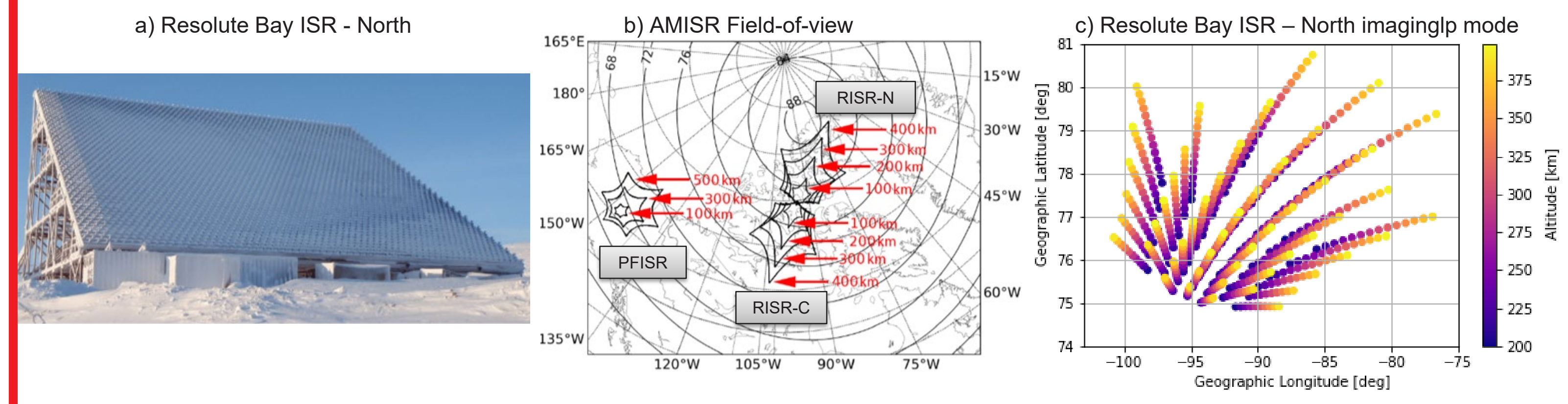

Figure 1: a) Resolute Bay ISR-North. b) The fields-of-view of the three high-latitude AMISR systems. c) Resolute Bay ISR-North imagingplp mode measurement positions.

- AMISRs utilize an array of antennae and electronic beam steering to observe multiple directions nearly simultaneously, making them powerful instruments to examine the upper atmosphere.
- AMISRs have a high-spatial resolution along a beam, but we will improve the spatial resolution at a given altitude by assuming that between 200 km and 400 km (in the F-region): 1) the magnetic field is nearly vertical, 2) that diffusion is the dominant transport mechanism parallel to magnetic field lines, and 3) that cross-field plasma diffusion at scales greater than 10 km is slow.

Method for mapping a given measurement to 350 km:

1. For a given measurement between 200 and 400 km altitude, we collect every other measurement that is: a) between 175 and 425 km altitude, and b) sits on a magnetic field-line that is within 50 km horizontally of the given measurement's field-line at 350 km altitude.
2. If there is at least one collected data point every 25 km altitudes, a spline is generated.
3. The given measurement is multiplied by the ratio between the spline plasma density at 350 km altitude and the spline plasma density at the altitude of the given measurement.

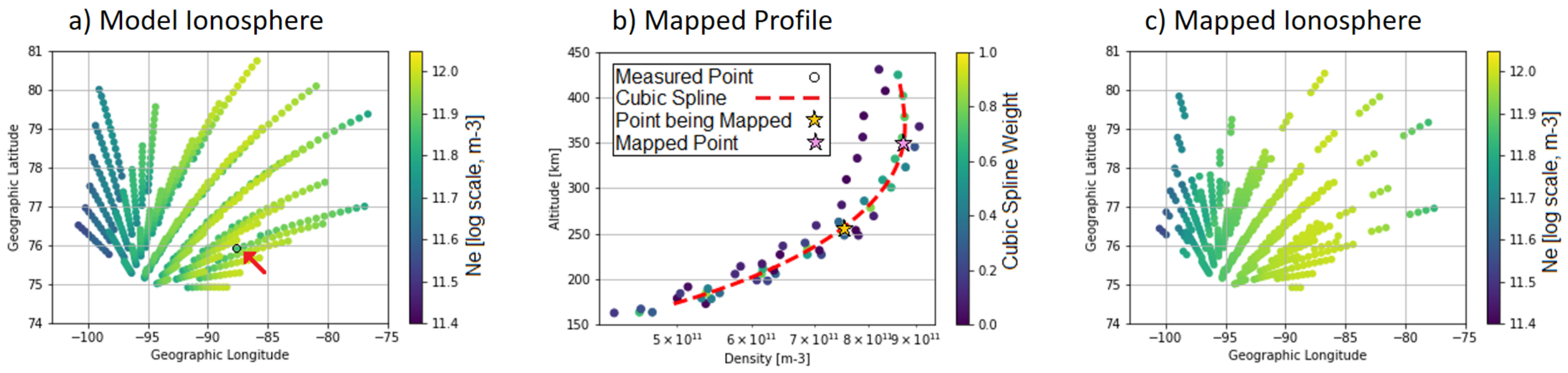

Figure 2: a) A model ionosphere containing a "Chapman" background density profile and a longitudinal density variation, sampled with the imagingplp mode, b) a plasma density profile created to "map" the value highlighted in panel a to 350 km, and c) the "mapped ionosphere", where every point is mapped to 350 km. Points mapped with an insufficient amount of data are removed, and points measured near 350 km are included as is.

Method for computing an irregularity spectrum in a mapped ionosphere:

1. Collect the "along-track" mapped plasma densities between two points of interest.
2. Calculate the Lomb-Scargle periodogram of the along-track mapped plasma density.
3. Remove features resulting from sampling irregularly by subtracting the Lomb-Scargle periodogram of a constant/uniform density sampled at the same locations as the mapped densities.

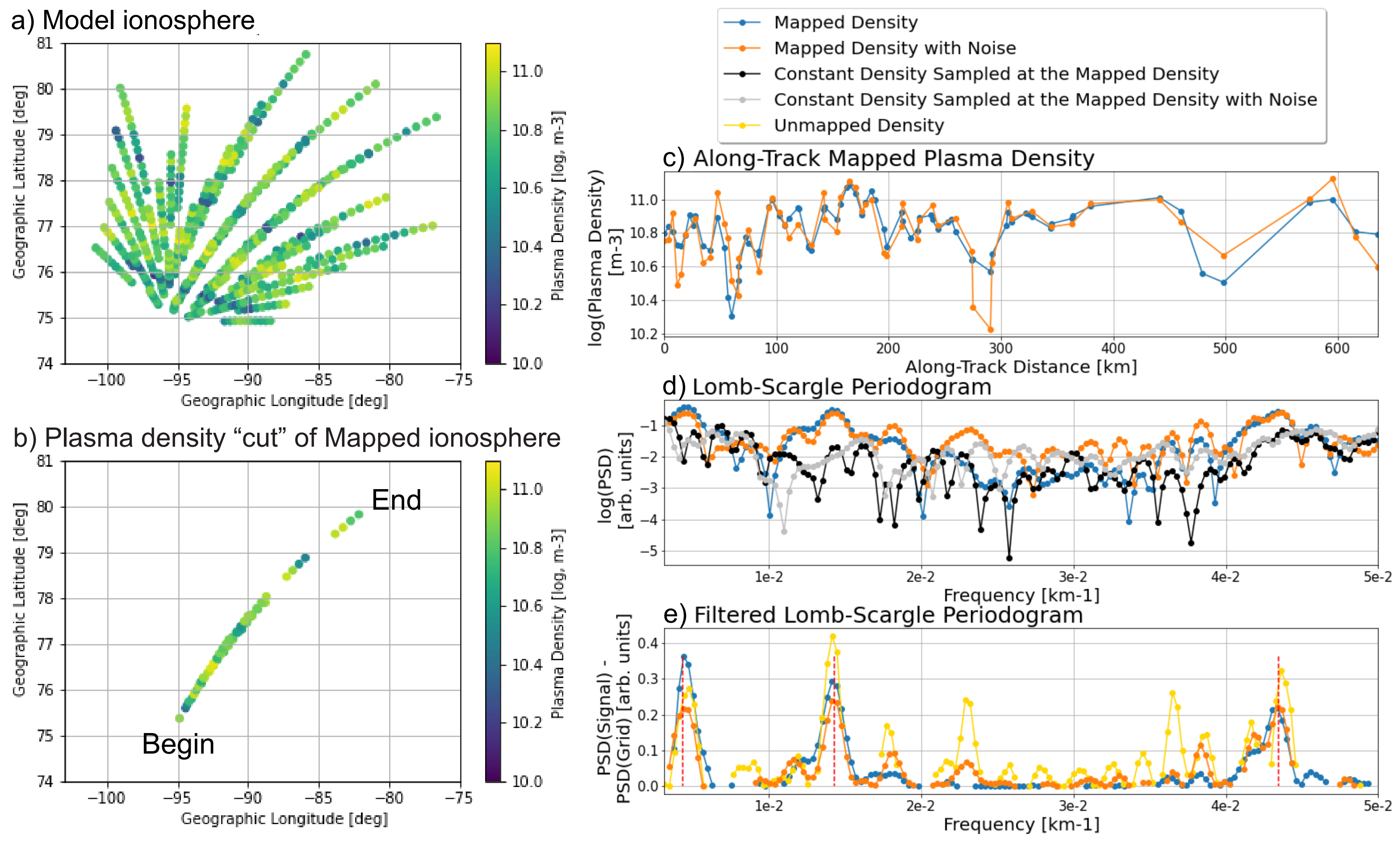

Figure 3: a) A sampled model ionosphere, containing a Chapman background density profile and three Sine waves ($f_1 = 1/(23\text{ km})$, $f_2 = 1/(70\text{ km})$, and $f_3 = 1/(230\text{ km})$). b) A selection of the mapped ionosphere at 350 km, c) The along-track plasma density from "Begin" to "End" in panel a, d) the Lomb-Scargle periodogram of panel c, and e) the filtered Lomb-Scargle periodogram. Red lines indicate the input spatial frequencies.

OBSERVATIONS

- The imagingplp mode ran for 4600 h on RISR-N from 2016 to 2018
- The largest spatial structure within an irregularity spectrum is selected for a given time, and the corresponding solar and geophysical conditions are recorded to determine the ideal conditions for a given plasma density variation.

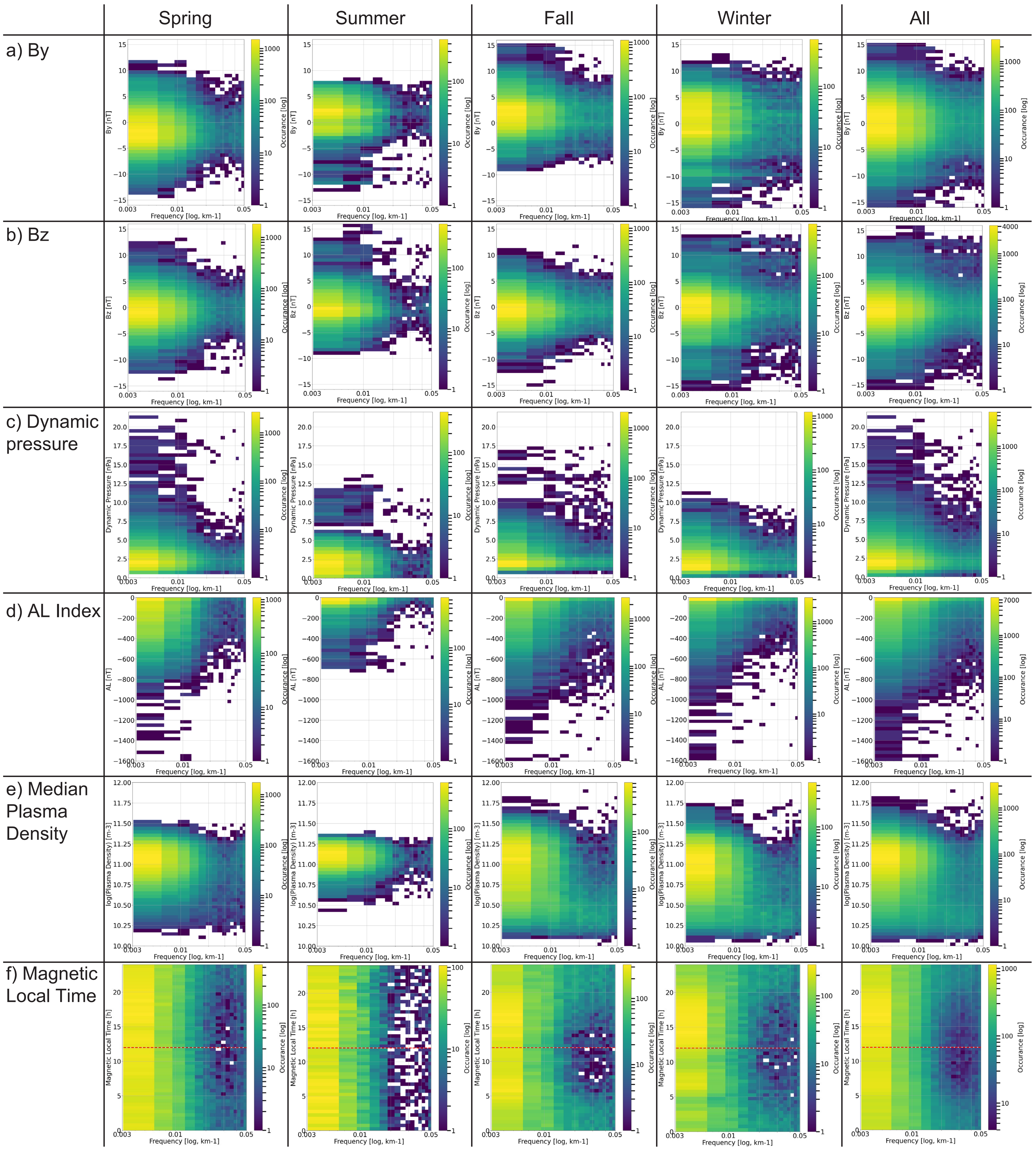

Figure 6: Monitoring the largest spatial structure for a variety of conditions and seasons using 2016 - 2018 RISR-N imagingplp mode data (approximately 4600 h of data, with 890 h in spring, 225 h in summer, 650 h in fall, and 517 h in winter). a) B_y (dusk-dawn component of the interplanetary magnetic field), b) B_z (north-south component of the interplanetary magnetic field), c) dynamic pressure (solar wind pressure), d) AL index (high-latitude hall current strength), e) median plasma density, and f) magnetic local time.

CONCLUSIONS

- Using novel ISR techniques and observation methods, high-latitude irregularities are resolved at a finer spatio-temporal resolution than has been previously possible with ground-based observations.
- This technique can be used to characterize polar cap plasma density variations, which models do not sufficiently characterize (particularly during transient events).
- Here, this technique is applied to an ISR experiment to gain better insight into the type of plasma density structuring resulting during a variety of solar and geomagnetic conditions.
- Small-scale structures (<50km) occur more during periods of quiet geomagnetic activity, at low densities, and from dusk to dawn (with some seasonal variations).

Future Work: Examine corresponding radio propagation data.

Acknowledgements: LVG is supported by the NASA Living With a Star Jack Eddy Postdoctoral Fellowship Program, administered by UCAR's Cooperative Programs for the Advancement of Earth System Science (CPAESS) under award #NNX16AK22G.